Leading Cats: How to Effectively Command Collectives

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ABSTRACT

The purpose of this work is to enhance the understanding of command and control in collectives, paying particular attention to coalition situations when multiple, typically autonomous agencies are expected to work together harmoniously. There are two different approaches to dealing with commands, one approach focuses on individual command components and the other studies the interplay between different commands. This paper is a first attempt at bringing these two views together, with the aim of understanding what is needed for human autonomous systems to work as collectives through command and control systems that achieve their full capability through "command by intent", while also encouraging and encompassing new agile behaviour both at the individual and organizational level. We have identified key aspects of commands in collectives (both from existing literature and from our own work) and demonstrate our findings in case studies taken from hurricane Katrina, 1995 Oklahoma city bombings, the 2001 attack on the Pentagon, as well as some incidents of lower complexity, such as an oil spillage on a motorway.

Key Words

Command by intent, command and control, collectives, multiple agencies, disaster response

INTRODUCTION

This paper aims at aiding multiple agencies collaboration during emergency crisis response management. It is known that this collaboration is difficult due to, amongst other factors, different command structures and different organizational process.

When disaster strikes, many different organizations, which under other circumstances work alone, are thrown together and would ideally work harmoniously as one, though in practice this is near impossible. This poses many difficulties, as typically the individuals belonging to an organization have been trained within that organizational structure, understand that particular organizational doctrine, and joint training is not seen very often. During this collaboration the organizations must focus on information sharing (which poses its own problems), collaboration and coordination. Work in this direction has already been initiated by Brehmer (2011) who established a new concept of command and control (C2) called Harmonization of Efforts. This aims at situations in which several organizations who typically operate autonomously are somehow involved. A central command is not available in such circumstances and Harmony of Efforts is what the present authors call the capability of the system, the maximum a *collective* could achieve (collectives for the purpose of our work are aggregations which can contain a mixture of humans, autonomous systems, organizations, etc.). The lack of a commander in these circumstances makes it particularly difficult to achieve "mutual support". Brehmer's Harmony of Effort is decomposed into three parts: the "spirit" in which C2 should take place, the method to be used and what C2 is about. Brehmer uses, as motivation for Harmonization of Efforts, studies conducted over 30 years in UN peace support operations, in these operations unity of command and unity of effort is inappropriate. The type of situations we have observed in the case studies, also have as maximum capability Harmonization of Efforts, and we will mention reasons why it is/is not achieved.

There are two main streams to modeling command. What we call a higher conceptual level approach considers command itself and the impact of one command on another, this approach does little in the way of

understanding the details of a single command, but provides accurate and complete models for understanding command interactions. Prominent examples of this are given by Kalloniatis work (2008) which aims to understand the synchronization of commands, and also by some military descriptions of the nature of command (Hayes and Alberts 2006;), (Moffat 2011). The other approach is at a lower conceptual level, typically a grammatical decomposition of elements of command. These grammatical models accurately depict a single command, but fail to encompass the broader notion of a command itself and so cannot be used to accurately describe how different commands come together and what causes different commands to be issued at in different situations. Focusing on a "single" command is unrealistic as command and control always happen in a broader setting where commands impact and are impacted by other aspects of the system. An encompassment of these two views will be crucial to our understanding of what are the central notions in *defining commands in collectives*. To understand commands in a collective setting consequently requires us to understand how to achieve "command by intent". Commander's intent is defined by the U.S. Department of Defense as "a clear and concise expression of the purpose of the operation and the desired military end state that supports mission command, provides focus to the staff, and helps subordinate and supporting commanders act to achieve the commander's desired results without further orders, even when the operation does not unfold as planned." The ability to command with intent welcomes new methods by allowing a command to be passed in a generic "what to do" as opposed to a specific "how to do it". Understanding command by intent requires a structure (not necessarily hierarchical) of intent that demonstrates the causal dependency relation between different components, and a formalization that allows for improvisation points and novel behaviours to be apparent. Another point is that the collectives observed during emergency response are entirely or partially dynamic, from rights of decisions to the nature of command itself, these are constantly evolving. The dynamic nature of command approaches is encompassed in many models but what they miss is the addition of the learning nature of the system itself, not just at the individual but at the collective level, of for example how a collective learns to recognize a novel expression of command and what it means. This paper proceeds as follows: first we highlight relevant literature, then give a workable Research Question of what command in collectives needs to encompass, then we proceed to exemplify these with case studies of varying complexities, and we conclude with a summary re-visiting our Research Question about commands in collectives, given the insight gained from the case studies.

RELEVANT LITERATURE

We have observed that models of command and control can be classified according to their level of conceptual abstraction; at the highest level are mathematical models describing the interactions between different commands and at the lowest level decompositions of individual commands. Figure 1 provides the reader with a perspective as to where each model of command lies in our conceptual space. What we mean by less abstract is that they are closer to being "just a grammatical decomposition", closer to dealing with what is being modeled, with actual commands, and so at this "level" it is possible to talk about aspects of commands. Seeing as the ability to "command by intent" has recently gained military focus, and is one of the areas we explore in this, the reader will find in green, areas that are able to incorporate intent in their models of command. What we mean is that in these models, for example in grammatical decompositions of command, intent is dealt with, these models are able to incorporate the notion of intent in them, whereas the mathematical levels, which are much more abstract are not, these models treat commands as abstract objects and are thus unable to incorporate a lot of aspects of real commands.

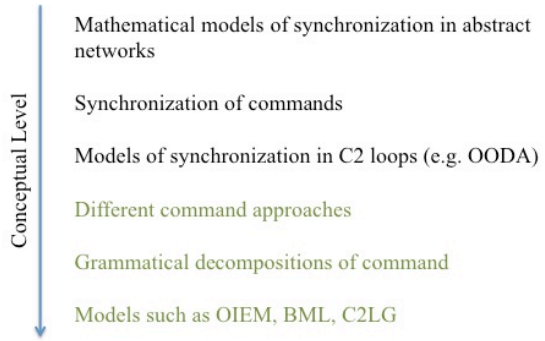

Figure 1. Conceptual Space of Command Models

Starting from the highest level of conceptual abstraction, Kalloniatis (2010) studies the mathematics behind a system's ability to achieve self-synchronization. This is a key concept to coherent, robust behaviour observed in collectives (for example animal collectives see (Couzin, 2009)). It is interesting to note that even with a strictly mathematical view, the author observes, through simulations, the existence of an intermediate step, between incoherence and synchronization. In those cases the networks showed periodic behaviours. If we see collectives as incoherent systems that on some occasions synchronize, then since this synchronization is crucial to achieving command by intent (Moffat, 2010). This must be present in non-linear descriptions of command and collective behaviour (by non-linear we mean not a "single command" and not the grammar of a command).

Kalloniatis (2008) applies the theory of self-synchronization to C2. This work is interested in modeling interaction between different C2 approaches and even though this coincides with the higher level view of command, his models do allow for the distinction of "time scales and interactions between individual processes". This work is based on the (well established) Kuramoto model (created to study synchronization in systems); the work alters and interprets Kuramoto's model to describe intra-node interaction within C2 processes. The model is interested in the transition from incoherence to synchrony and it copes with the notion of partial synchrony: some elements in the system form synchronous "clusters" while the remaining behave randomly with respect to these clusters. Kalloniatis (2008) argues that C2 naturally happens in cycles, e.g. Boyd's (1987) Observe-Orient-Decide-Act (OODA) loop. There are two notions which are abstracted in terms of synchronizable processes: the winning team will outpace the enemy's OODA loop and within each team's command system, all decision cycles must synchronize with respect to time and so that decisions interdependent on each other don't occur in parallel. Another example is given by MAP (Military Appreciation Process) sequence: Scoping -> Mission Analysis -> Course of Action Development -> Course of Action Analysis -> Decision -> Execute. Alberts and Hayes (2006) add to this by discussing ways to measure the quality of command through measurement of quality of intent, the quality of information passing. Albert and Hayes also acknowledge the limitations with this approach, for example the quality of intent might be limited by its expression and its degree of acceptance.

Synchronization depends on political, social, adversarial and environmental constrains. MAP and OODA loops are mapped as continuous circular decision loops which need to synchronize, both locally and across networks. Brehmer (2006) introduced the concept of a Dynamic OODA (DOODA) loop, this model incorporates sensemaking, planning and information gathering. Synchronization has clearly been well studied with regards to command. Moreover with regards to abstract networks, from a mathematical, sociological and psychological point of view, many aspects have been thoroughly thought-out. Most of these describe behaviour that should be taken into account when dealing with command and control systems. An important point is to be able to predict when command clashes will occur stopping systems from reaching their full capability. Once we have understood commands as decomposable structures in terms of intentions, goals, commands and methods we can begin to understand how these elements might be in conflict.

Finally, we begin our exploration of current models of command from a lower conceptual level of abstraction, i.e. those that try to understand individual commands and what comprises them. Examples can be found in the development of battle management language (Hieb and Schade 2007) or the C2 grammar (Hieb and Schade 2008). Hiebe and Schade have a formalism for C2, termed the Command and Control Lexical Grammar (C2LG), they focus on trying to define a formal and unambiguous language, which can facilitate military communication amongst human and machine agents. Their grammar is broken down into two grammars: a "tasking grammar" and a "reporting grammar", these are then used to express command by intent. Hieb and Schade (2008) decompose command by intent in terms of Purpose, Key Tasks, End State. Hieb and Schade (2008) define, the Command and Control Lexical Grammar (C2LG), in which their aim is to give a formal and unambiguous language which can facilitate military communication amongst human and machine agents. They develop a "tasking grammar" and a "reporting grammar", and then use these to express command by intent. Command by intent is decomposed in terms of Purpose, Key Tasks, End State. The basic order expression is composed of a tasking verb (JC3IEDM's table "action-task-activity-code", for example defend, attack) and its frame (the form being Verb Tasker Taskee (Affected|Action) Where Start-When (End-When) Why Label (Mod)*) where Mod is a place where any additional information can go, this is also present in reporting expressions. In (Alberts and Hayes 2006) it is understood that the acquisition of command can happen "whether by law, regulation, practice, role, merit, or force of personality". And the styles of organizations involved in command will impact it, by styles it is meant experience, risk taking, use of power and force, diplomacy, ethics, norms, morale, creativity, unorthodox behaviour. Moreover, "Command and Control does not encompass all of the decisions made by individuals or organizations nor all of the decisions that emerge from collective behavior; only the ones directly associated with the functions of C2." We will use this to hypothesise on the importance of a clear understanding of the doctrine and goals, intents at the organizational level when issuing commands in coalition environments. Some progress has also been made by Gustavsson, Hieb, Moore, Eriksson and Kiklasson (2011) which provides a model that encompasses intent and effects together with a formalism that can be read by machine and humans.

The formalism is similar to the battle management language but crucially it incorporates intent and effects, it is described in Lexical Functional Grammar (LFG) and we now briefly discuss its components. Intent is decomposed as: Goals, End state, Sequence, State, Key decisions, Anti-goals, Constraints, Expressives (cultural and doctrinal behaviors). For this work state is broken into physical state, cognitive state and status state, similar to different domains as specified by Moffat (2011). There is, however, a classification difference in these two views: Moffat views these as part of a hierarchical structure, whereas Gustavsson et al. (2011) see them all at the same level, so they define a linear structure.

A different, but related area to command modeling, is that of command analysis. So far we have looked at theoretical models of commands. We now look at how to analyse commands as they occur during emergencies. Trnka and Johansson (2009) present documented practice of commanders responding to emergencies. They used episodic analysis, socio-metric status and communication roles for their analysis and found that commanders use informal and innovative communication means, this is in accordance with what we have found in our case studies (to be described at a later section). An interesting point made here is the cross-organizational knowledge as an important factor for coordination, which again formalizes what we found with our own case studies. A slightly different take on improvisation can be seen in the work by Rankin, Dahlbäck and Lundberg (2011) this time dealing with "improvised roles" (which we have found in one of our case studies, see (Montoya 2007)). In this work, the authors aim to understand improvisation by analyzing a case study of crisis management response collective "as they work" and looking deeply into information and communication of individuals with improvised roles. An interesting approach to understanding failures in disaster management is given by Bosse, Hoogendoorn, Jonker and Treur J (2008) where they conduct empirical analysis on nonmonotonic reasoning processes in the context of incident management, trying to understand how people reason under pressure. The authors provide a generic formalization of how people reason towards an interpretation. Simulations were tested against empirical results and found to be adequate.

COMMAND IN COLLECTIVES

We will now describe crucial aspects necessary for successful command during coalition situations. Our thesis is that (at least) these elements must be present for a successful command and control system during emergency response. Our claims are inspired by literature as well as original thinking and reinforced by case studies of varying complexities. We will look at:

- Human Bias (since this is sufficiently self-explanatory, we leave this analysis to the Case Studies section only).
- Flexibility.
- A (lack of) understanding of the interplay between: different commands, different elements of different commands (broken down further and parts given by case studies, parts left as theses).
- Temporal classification of command (case studies), communication structures (literature), sensemaking (literature)
- A structure of intent (theoretical work).
- A (lack of) understanding of organizational doctrine, house rules (which we define as expected ways of achieving certain goals, carrying out certain instructions) and organizational and individual culture (broken down and parts given by case studies, parts left as theses).

We will briefly take each of these and explain in greater detail. Before we go any further it seems sensible to inform the reader that we are taking a very elementary way to judge whether a command is a failure or a success. A failure is given by a command that does not satisfy the local requirements imposed by the situation and understood by the stakeholders. Successful commands for our purposes are those commands that are not failures.

The case studies chosen were such that they fitted this very obvious criteria, we are aware that more sophisticated approaches could have been taken to explicate varying complexities of "good/successful" or "bad/failure" commands; but that is beyond the scope of this paper. This is left for future work after we have understood these in the basic level we have done in the cases outlined. Before we proceed any further it is necessary to explicate that by *command in collectives* we mean commands taking place in a large system, a collective which could encompass organizations and individuals (as well autonomous entities), that are involved in the same situation (we deal only with disaster response management) whether explicitly stated or not. This is in contrast with a *collective of commands,* meaning several commands. Another concept that is important to us is that of flexibility, by which we mean resilience to change. The capacity for collectives to adapt to nouveau behaviour is not always present and it is essential in establishing successful command structures, capable of adapting to new situations and unexpected changes. This kind of resilience should be a crucial consideration in

collaborations and in the development of new technologies for crisis management.

In keeping with our desire to integrate higher and lower conceptual descriptions of command, we hypothesise that a lack of understanding of the interplay between: different commands, different elements of different commands, commands and elements of other commands are amongst the underlying causes of failures, such as communication breakdowns. By elements of a single command we mean the usual understanding of what comprises a command: a mission statement, goals, anti-goals, time constraints, commander's intent, explicit method for achieving certain goals. We formulate that the better the structure of the overall system and understanding of different elements, the less the need for "explicit methods" for achieving goals and the higher the level of "command by intent". By system we mean the entire collaboration effort which includes all the stakeholders involved.

A structure of intent in an attempt to make clear what is absolutely essential to be satisfied for successfully commanding collectives. A "single" intent comprises several different levels of intention, and these need to be explicit, not necessarily hierarchically. The structure must contain causal dependency relations between the (visible)[1] intentions that comprise the intent being structured. Specifying what formalism the structure should be presented in is beyond the scope of this paper; this will depend, amongst other factors, on doctrine and culture of organizations involved. For a very simple example of how one might consider the different intentions comprising a single intent, consider the intent "to make you watch film X". I can break this down into "I intend for you to watch film X", " I intend to take you to the movies and see film X" amongst others. If I borrow that movie from a neighbor and lend it to you than one of the intentions was satisfied but not the other. Suppose the author of this intent structure wished for two things: 1-) for you to see that film and 2-) for you and him/her to watch it together at the movies. Then he/she should have put a dependency relation on these conditions so that you had to watch the movie and he/she had to be present and it had to be at the movies, that way if you watched the movie alone the intent was not satisfied, because one of the dependencies was broken.

Another necessary condition to command collectives of human and autonomous systems is a clear understanding of organizational doctrine, house rules (which we define as expected ways of achieving certain goals, carrying out certain instructions) and organizational and individual culture. This is important because these elements limit the number of command approaches available per crisis situation. During coalitions, such an understanding is crucial so that different organizations can predict what might not work. An important point is that there is a need for a learning system that detects human behaviour, and if the outcome is successful adds it to a/the? list of house rules.

Other aspects that are important for command and control in human autonomous collectives are communication structures, socially distributed cognition and the role of artifacts in sense making. These have been studied in the literature and a brief discussion of these follows, we include these to the list of important aspects for commands in collectives to form a successful system during emergency crisis management. It is important at this point to add that by a human autonomous systems (or collective, we will use these terms interchangeably) we mean a collection of humans (individuals and organizations) and entities capable of operating autonomously, examples are given by "intelligent" data mining programs, stock market exchange programs, as well as physical entities such as autonomous vehicles. The term system or collective is to indicate that human and autonomous entities are, in these cases, part of a large collaborative effort that must function harmoniously. An example of work done on understanding failures in communications during command is given by Asplund and Lundberg (2011); where specific aspects of communication are identified as important and their interplay studied, namely communication infrastructure, situation awareness, individual and organizational common ground, form and content of messages, and communication paths through organizations. The authors propose solutions to some of these. We add to the list of possible solutions they already mentioned, which include structure of command, intent, methods and goals. McMaster (2012) studies collaborative sensemaking through means of (both formal and informal) artifacts in police emergency response. This contributes to the area of understanding how information is shared in organizations taking a distributed cognition approach to it. Their data is gathered from studies in two (one urban, one in a rural area) UK Police forces between 2004 and 2010 and it shows the need for new ICT technology in police response, and moreover that it is important to take into account existing organizational doctrine and culture prior to imposing new technology.

Another example of work on the study of information exchange in emergency response is given by (Netten and Someren 2008); this work focuses on coarse-grained dialogue segmentation. They provide a method, which automatically recognizes coherent segments of textual information, exchanged during disasters. The "cut-off" points to each segment are based on interpretation by the human user, however once this is done they are

[1] The decomposition into intentions will vary according to who does the exercise, so by visible, we mean visible to that particular agent or organization.

automatically recognized. Another important area for achieving efficient command and control, which has already been vastly covered in the literature is sensemaking (e.g. (Weick, Sutcliffe, and Obstfeld 2005), (Weick 1988), (Weick 1993); (Landgren 2004); (Borglund and Nuldén 2008) and (Faisal, Attfield, Blandford 2009)).

Temporal Relations of Commands
Intent
Doctrine, organizational and individual culture
Communication Structures
Sensemaking
Human Bias
Flexibility
Interplay between different features and commands

Figure 2. Summary of command features

This classification aims to facilitate the identification of when commands might clash and when command approaches are inappropriate to the situation. Moreover, when new commands are issued or even when new individual goals appear, this structure should help in predicting their suitability within the whole system.

CASE STUDIES

We will now exemplify components of our hypotheses from the previous section in a retrospective analysis of some real world case studies; in addition these elements are analyzed in further detail as we apply them to understand successes and failures in the case studies. The reader will note that all individuals involved in our analysis have been mentioned anonymously.

A major failure in the command system during the aftermath of Hurricane Katrina was a rigid allocation of roles and inflexibility in command approach. Organizations and individuals have a set of command approaches to choose from, this set is bounded by doctrine of organization, culture and personal goals and intent, as well as organizational goals and intent. Each individual and each organization has a structure of goals and intents they wish to follow, some are more important than others, some are allowed to occur concurrently whereas others are co-dependent or dependent of completion of others; similarly to the typology on commands specified in the previous section. In complex situations such as during emergency response it is essential that organizations draw their structure as accurately, comprehensively and unambiguously as reasonably possible, especially because one of the reasons for failure in rescue operations is when these autonomous organizations suddenly have to work together. We hypothesise that this failure is due to more than simply "lack of training", that some of them could be prevented by a decomposition of organizational goals, command and intents into a clearly understandable set with the typology on commands as classified in Figure 2.

Human Bias

Even with such a structure in place, humans are still prone to bias and prejudice which will cause the right command to be followed at the wrong time. For example, during the aftermath of Hurricane Katrina, local police forces had, amongst others, the high level goal of rescuing people and keeping the peace, and it was the high level intent of the whole Katrina operation (both official and civilian individuals who interfered) to rescue people. An example of this is given by civilian X, who tried to rescue stranded neighbors with a personal canoe but was stopped by police who thought he was a acting maliciously (Pilkington, 2010), here the high level intent to save lives was blocked by the intent to keep the peace, simply because police officers interpreted X as a looter/potential terrorist.

Understanding (or lack thereof) of the interplay between commands and other elements and the overall structure of command and intent

A successful example of a clear understanding of the overall structure of command and intent leading to an appropriate selection of intents and goals lying in the intersection of "most important " and "most relevant to current situation" is that observed in the behaviour of Sergeants A and B. When they heard the news of the hurricane, they borrowed a boat and contacted their commanding officer, who gave them the necessary permission to proceed to New Orleans (5 hours away), and assist the Red Cross with its rescue mission. The original mission was to rescue those stranded in hospitals and infirmaries, however on the journey they noticed people in attics, rooftops and cars and opted to rescue them instead. An understanding of the cooperation of

commands and how the overall intent here prevailed over the lower level intent the marines had to follow during their mission caused them to alter their behaviour in a way that lead to the successful rescue of trapped citizens (Murphy 2005).

Flexibility: Limitations due to complexity

The creation of a structure with the typology as described becomes increasingly difficult with an increase in complexity of the situation.[2]

For example, one can contrast Katrina with the 2001 attack on the Pentagon and the 1995 Oklahoma City bombings (Moynihan 2007) and notice that a lower complexity of the two last mentioned events allowed for a quick assignment of, amongst other things, command roles. The command approaches were sufficiently flexible to break the traditional hierarchical imposition; nonetheless a centralized command structure was established, as required in the ICS (incident command system). In the pentagon, federal organizations did not impose their authority. An example of the opposite causing a clash between federal and local authorities is given by the case of a federal organization (see (Interview 2005)) cutting their emergency communication lines of a local parish, causing a local authority to reconnect the line and post armed guards so that no one could disconnect them again. This can also be used as a motivating example for the need of the aforementioned structure of command, goals and intents. Although one thing to note is that since it was unclear the reason behind federal organization's decision to cut the lines, there might be more complexity layers to this story. In that case, this is a motivating example that such a structure can highlight when a clash might occur (a simple example is federal agency imposing their authority and the local authority imposing their right to keep their communication lines opened) but it does not provide a mechanism for avoiding it. The creation of such a mechanism is beyond the scope of this paper, but we would expect that collective decision rationale studies would provide good insight to the design of clash avoidance solutions.

In the Pentagon case, there was a general perception of there having been clashes between federal and local organizations and a proper authority not being established, despite the formal mechanisms to achieve this. This is a good example of how important it is for the system of commands to be a *learning system* which robustly adapts to new ways of achieving goals and intents even by breaking house rules, these new methods if successful should become part of the house rules. One thing to note is that we are deliberately not talking about how to say that one method is quantifiably better than another; we think this can be given a very simple of solution by saying: if the new method is not worse than the expected method, it gets added to the list of known methods (or house rules). That way we skip the complexity issues that arise in trying to quantify these components, but acknowledge that such a simple solution might not be appropriate to all circumstances.

Flexibility in assigned command roles

A good example of flexibility in assigned command roles is given by what happened in the aftermath of the 2001 attack on the Pentagon. The assistant chief of Fire Department X arrived at the scene before his commanding chief and took command and control over the situation; the chief of the Fire Department arrived shortly after and opted not to relieve his assistant chief from command. Moynihan (2007) attributes a lot of the success in this particular operation to the flexibility in commander's roles pre-imposed by the ICS procedure. We hypothesise that as well as a flexibility in command roles pre-imposed by the command system, the success of the management of this particular crisis was facilitated by a correct choosing of the right command approach at the right time (from a set limited by conditions already explored above), and due to sensible human decision-making. For example, the assistant chief opted out of a traditional choosing for incident commanders from his own organization, and instead placed officers from other departments in places where he thought would benefit from their particular expertise. Unlike the Oklahoma city bombings (in which there was a protective reaction of officers with regards to their role towards federal organizations), the assistant chief chose to incorporate them into the command structure; for example, he said "On our incident, I knew I wanted to know where FEMA[3] was all the time, and I figured the best way to do that, as well as get their expertise, was to have them up there with me in the command post. I was just looking for practical solutions. I didn't want something that some book said you shouldn't do getting in the way of what I thought was the best way to deal with this" (Varley 2003). Breaking house rules as to how key officers are typically placed in authority positions and how to incorporate federal organizations into a local response should be automatically incorporated into the system as house rules, given their success, and then added to the acceptable set of command approaches; this neatly exemplifies what

[2] A detailed description of what entails complexity with regards to crisis management is beyond the scope of this paper. However, we note that complexity could be measured as a mixture of number of stakeholders, number of agencies involved, degree of geographic distribution of agencies and geographic distribution of the disaster/catastrophe/etc. itself, level of warning before major incidents, amongst others.

[3] FEMA stands for Federal Emergency Management Agency

we mean by a learning system.

The case of command hand over is not an isolated one; there are examples (Case Studies 2012) of Fire and Rescue Service teams handing command over to a private organization to restore back order in incidents such as a tank colliding and spilling oil in a motorway, a tank venting steam of acetic acid in a brewery. There are also examples of incidents being immediately tended to by a private organization; for example when a manufacturing company accidentally released engine oil into a storm drain. As already noted, the ICS protocol has a high level of flexibility in command built into it, but nonetheless it requires the formation of a centralized command and is thus not appropriate for all situations. This type of centralized command seems to work well with multi-organizations cooperation of a relatively small scale or within an organization, for example Bigley and Roberts (2001) observed the successful installment of the ICS in a California fire department. Further we have observed that it requires a quick installation of "leaders", but typically it comes down to human nature whether the flexibility of "who is in charge" will be accepted or not. So this approach might not translate as well to multi-organization situations of high complexity requiring a more distributed or an emergent type of command.

We have examined how an increase in complexity is proportional to difficulty in establishing certain key aspects of command in collectives. The reader must note however that this is just an untested thesis and further comparative work on this type of centralized command protocols must be done for conclusive results to be drawn.

Beyond complexity: other considerations

We now analyse two aspects that seem independent on the complexity of the system.

Lack of understanding of goals and intents

There are certain components that seem to be independent of complexity. For instance, the inability for multiple autonomous agencies to work collaboratively still fails even in local and contained disasters[4] of less complexity (as compared to Katrina), such as the 1995 Oklahoma City bombings (Moynihan, 2007). Members of a police force noted that their department was unprepared to incorporate all the volunteers into their missions, and no accepted procedure to deal with donated material was put in place. A member of the Red Cross coordinating team noted similar unpreparedness to deal with the "overwhelming" number of volunteers. We stand by our thesis that this could be facilitated by laying out the structures we have specified and sharing them amongst all stakeholders. In addition each individual involved should similarly structure his/her own intent and goals and analyse them against the organizational ones and the higher level "system" structures.

A clear understanding of necessary goals and intents, house rules: when the right command structure meets the demands of the system's capability

For another successful command story, we refer the reader to the case of Civilian Y, (Montoya, 2007), an ex-marine who was amongst hundreds of people trapped in a building; he successfully set up command and organized food distribution, protection to all good-intending residents as well ensuring their evacuation. We suggest that this particular situation called for a hierarchical, hero emergent type of command, and so the right command structure was chosen in the right circumstance, at the right time. His previous military experience and large, imposing figure probably made him an ideal candidate to become a leader for the apartment complex; no other type of command structure would have been appropriate. In addition, his obtaining of power was facilitated by people in the building being scared and seeking an authority figure as a means to relive them of some responsibility for decision making during the crisis. A similar successful example of the right command structure meeting the demands of the system's capability (again in this case an emergent hero type) can be found in (Rodríguez, Trainor and Quarantelli 2006). An emergent group, consisting of eleven friends, searched for survivors and food to re-distribute to those in need; they came up with their own rules such as no bodies were to be retrieved, only survivors and no weapons were to be carried. Interestingly the group had informal cooperation understandings with the police and the National Guard, for example these organizations passed them ready meals to distribute as well as survivors who wished to evacuate. They had been childhood friends and the familiarity amongst teammates made it possible for the group to emerge and develop its own doctrine rapidly. The fact that the National Guard and the police were willing to form an ad-hoc coalition with a non-official team shows flexibility in the system and if the system is to learn new behaviour, then this should certainly be one. There has been considerable work on teamwork and how to improve this type of cooperation and coordination amongst individuals in these groups, see for example (Gibson and Zellmer-Bruhn 2001); (Morey et al. 2002); (Tremblay et al. 2012). We end with a success story; on Sunday 11 December 2005, an oil storage facility, the

[4] By disaster we mean any human or natural incident requiring multiple agencies coordinated emergency response and pay no attention to the classifications into catastrophe, disaster, etc. seeing as they differ according to culture.

Hertfordshire Oil Storage Terminal, near an English motorway, the M1 saw a series of explosions that eventually took down twenty large storage tanks (report 2011). The response to this particular crisis situation has been quoted as an example of how the bronze –silver –gold command structure (McCann 2009) is defined. The structure was created in 1985 and has been applied at different incidents since. The fact that the system had been placed in practice a few times contributed to its success; this is similar to the American ICS, which was created in 1968.

CONCLUSION

We have identified a few *key aspects of command in collectives* that must be present for the *capability of a system of emergency response to be achieved*. By no means are we claiming that this list is comprehensive, we have pursued a detailed analysis of some elements, inspired by literature and our own thinking, and have tested these against case studies. The appearance of new technology and the constant evolution seen in human nature means that this list will never be truly comprehensive; nonetheless one can hope to keep it as up-to-date as possible through further analysis of case studies and potential field work. Our case studies dealt with three different types of commands; distributed, emergent, hierarchical. This is by no means a fully comprehensive list, but even such a stringent division has allowed us to confirm that *different approaches to command are required in different situations* even when the same organizations are involved. This suggests that organizations need a *high degree of flexibility in command when cooperating* with other stakeholders. We have also observed some *limitations to each command approach*, for example *doctrine and culture of organizations and individuals* involved, time constraints, differing goals, intent. This suggests the need for all stakeholders to create a structure of goals, intents and have clearly defined doctrines so that these can be shared at the system level ensuring that only "reasonable" command methods are put forward. It is unrealistic to expect that a subset of this structure would generate common goals, intents, etc. but the hope is that by drawing it as a *causal dependency relational set*, once can predict which components might clash and create a rationale for solving conflicts before they arise. A next step in this work will be the *creation of a formal grammar*, which would build on the *current command grammar* used in the military; so that it encompasses our working definition of command in collectives. This should be done without deviation from regular grammars, in order to ensure whatever language built on the grammar can be *automated and enhance human-autonomous system communications*. One possible starting direction is in the work done in developing the language IEML (Lévy, 2006) for collective intelligence research. This encompasses many of the desired notions and is being build for a more general setting than the grammars built in the military setting which are mainly aiming at time-bounded military missions; whereas we wish to be able to deal with command in a more general, "on-going" dynamic and complex setting.

ACKNOWLEDGMENTS

The research reported here benefited from funding from EPSRC EP/J012521/1 Human Autonomous Systems Collective Capability (HASCC), we are grateful to the EPSRC for this funding. We are very grateful for the anonymous reviewer's comments that greatly improved on the readability and quality of this paper.

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